Does Coarse Thinking Matter for Option Pricing? Evidence from an Experiment

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19. February 2009

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Abstract

Mullainathan et al [Quarterly Journal of Economics, May 2008] present a model of coarse thinking or analogy based thinking. The essential idea behind coarse thinking is that people put situations into categories and the values assigned to attributes in a given situation are affected by the values of corresponding attributes in other co-categorized situations. We test this hypothesis in an experiment on financial options against the benchmark of arbitrage-free pricing. Firstly, we test whether a financial option is priced in analogy with its underlying stock (*transference)*. Secondly, we test for whether variations in the analogy between a financial option and its underlying stock matter (*framing*). We find evidence in support of both *transference* and *framing.*

Keywords: *Coarse Thinking, Financial Options, Arbitrage-Free Pricing.*

JEL Classification: C91, G12, G14

Does Coarse Thinking Matter for Derivative Pricing? Evidence from an Experiment

In an interesting paper, Mullainathan, Schwartzsein & Shleifer (2008) put forward a model of coarse thinking. Their model is based on the notion that agents use analogies for assigning values to attributes (the attribute valued in their model is "quality"). The defining idea behind coarse thinking is that agents co-categorize situations that they consider to be analogous and assessment of attributes in a given situation is affected by other situations in the same category. This is in contrast with rational (Bayesian) thinking in which each situation is evaluated according to its own merits. Even though coarse thinking appears to be a natural way of modeling how humans process information (Kahneman & Tversky (1982), Lakoff (1987), Edelmen (1992), Zaltman (1997), and Carpenter, Glazer, & Nakamoto (1994)), empirical evidence on the issue is difficult to gather. It is clearly difficult to isolate coarse thinking from confounding explanations. However, experimental methods appear to be particularly suited for this task due to greater control that they offer.

Mullainathan et al (2008) use the advertising theme of Alberto Culver Natural Silk Shampoo as a motivating example to explain coarse thinking. The shampoo was advertised with a slogan "We put silk in the bottle." The company actually put some silk in the shampoo. However, as conceded by the company spokesman, silk does not do anything for hair (Carpenter et al (1994)). Then, why did the company put silk in the shampoo? Mullainathan et al (2008) write that the company was relying on the fact that consumers co-categorize shampoo with hair. This co-categorization leads consumers to value "silk" in shampoo because they value "silky" in hair (clearly not a rational response). That is, a positive trait from hair is transferred to shampoo by adding silk to it. Such transfer of the informational content of an attribute across co-categorized situations is termed *transference*. An important question is, how are categories formed in the first place? A natural response is to say that clues about category formation must come from the description of the situation under consideration. Mullainathan et al (2008) call such inference *framing*. The way a situation is described or framed affects its subsequent categorization. Hence, *framing* and *transference* are two concepts associated with coarse thinking.

In this paper, we address the question of whether the way investors price financial options in a controlled laboratory experiment is affected by coarse thinking. We use a simple framework that allows us to distinguish between the hypotheses of coarse thinking and arbitrage-free pricing. We find that the hypothesis of coarse thinking has a significantly greater explanatory power over the benchmark of arbitrage-free pricing. We find evidence in favor of *framing* as well as *transference.*

Coarse thinking or analogy based reasoning is likely to play an important role in understanding financial market behavior. Many researchers have pointed out that there appears to be clear departures from Bayesian thinking (Babcock & Loewenstein (1997), Babcock, Wang, & Loewenstein (1996), Hogarth & Einhorn (1992), Kahneman & Frederick (2002), Kahneman, Slovic, & Tversky (1982)). Such departures from rational thinking have been measured both at the individual as well as the market level (Siddiqi (2008), Kluger & Wyatt (2004)). However, the question of what type of behavior to allow for if non-Bayesian behavior is admitted is a difficult one to address in the absence of an alternative which is amenable to systematic analysis. Coarse thinking may provide such an alternative especially when the intuitive appeal of analogy based reasoning is undeniable.

This paper is organized as follows. Section 2 explains the hypothesis of arbitrage-free pricing as well as the hypothesis of coarse thinking and derives each hypothesis's price predictions in the context of our experiment. Section 3 describes the experimental design. Section 4 discusses the results. Section 5 concludes.

2. Arbitrage-Free Pricing vs. Coarse Thinking

The concept of arbitrage-free pricing is based on the portfolio replication argument. The portfolio replication argument (also known as the law of one price) states that two portfolios with identical payoffs must be identically priced. According to this principle, in order to price an asset, one only needs to find a portfolio that exactly replicates the payoffs of the asset. The price of the asset in question must then be equal to the cost of the replicating portfolio. If this principle is violated then an arbitrage opportunity will arise. Portfolio replication argument forms the heart of modern asset pricing theory. As one example, the Black-Scholes option pricing formula derived in Black, Scholes, & Merton (1974) is an application of this principle.

2.1 Arbitrage-Free Pricing

Consider a call option with payoffs C_1, C_2, and C_3 corresponding to states Red (R), Blue (B), and Green (G). There other assets B_1, B_2, and B_3 with prices p_1, p_2, and p_3 are available. Table 1 shows the payoffs associated with each asset in each state. All payoffs are non-negative.

Table 1

Price	***Asset Type***	***State R***	***State B***	***State G***
?	Call	C_1	C_2	C_3
p_1	B_1	X_1	X_2	X_3
p_2	B_2	Y_1	Y_2	Y_3
p_3	B_3	Z	Z	Z

In order to calculate the arbitrage-free price of the call option, consider a (replicating) portfolio consisting of a units of B_1, b units of B_2, and c units of B_3 such that:

$$aX_1 + bY_1 + cZ = C_1,\ aX_2 + bY_2 + cZ = C_2,\ \&\ aX_3 + bY_3 + cZ = C_3$$

Given such a (payoff replicating) portfolio, according to the portfolio replication argument, the arbitrage-free price of the call option is $ap_1 + bp_2 + cp_3$. Hence, arbitrage-free price provides a sharply defined benchmark for rational pricing. This benchmark is the cornerstone of modern finance.

2.2 Option Pricing with Coarse Thinking

Suppose all three states are equally likely to occur.[1] The price of any asset with coarse thinking depends on how it is categorized. Suppose the call option we have been considering has B_1 as the underlying asset and has k as the striking price (a call option is an instrument that gives the buyer the right but not the obligation to purchase the underlying asset (B_1 in this case) at a specified price called the striking price k). For simplicity, assume one period marked by two points in time. The current time is date 0 and the option yields a payoff (expires) at date 1, at which point one of the three possible states is realized. It follows,

$$C_1 = \max\{(X_1 - k), 0\},\ C_2 = \max\{(X_2 - k), 0\},\ \&\ C_3 = \max\{(X_3 - k), 0\}$$

As can be seen, the payoffs in the three states depend on the payoffs from B_1 in the corresponding states. Furthermore, by appropriately changing the striking price k , the call option can be made more or less similar to the underlying instrument B_1, with the similarity becoming exact as k approaches zero (all payoffs are constrained to be non-negative).[2] A call option more similar to B_1 is more likely to be co-categorized with B_1 by coarse thinkers (*framing*).

We set up an alternative hypothesis to the arbitrage-free pricing as follows. Given co-categorization of the call option with B_1, coarse thinkers choose a price for the option that equates the expected return on the option with the expected return on B_1 (*transference*). That is, the attribute being transferred from B_1 to the call option is the expected return. A coarse thinker is solving for the price of the call option by analogy with the underlying stock. The underlying stock has a certain link between the payoffs and price, which is captured by the concept of expected return. While pricing with

[1] Knowledge of the likelihood of states is needed to derive the coarse thinking price. This information is not required to derive the arbitrage-free price.

[2] In the context of the portfolio replication argument, this similarity can be understood as being captured by the value of a in the replicating portfolio. Higher the value of a , higher is the similarity between the underlying instrument and the option being replicated.

analogy, it makes sense to transfer the same link to the asset being priced. Denoting the call price by P_C , the coarse thinking hypothesis with *transference* of expected return implies,

$$P_C = \frac{C_1 + C_2 + C_3}{X_1 + X_2 + X_3} \times p_1$$

The coarse thinking hypothesis provides a precisely defined alternative to the benchmark of arbitrage-free pricing. For comparison, table 2 shows prices under both hypotheses.

<u>Table 2</u>

Call Option Price

Coarse Thinking (Transference of Expected Return)	***Arbitrage-Free Pricing***
$P_C = \frac{C_1 + C_2 + C_3}{X_1 + X_2 + X_3} \times p_1$	$P_C = ap_1 + bp_2 + cp_3$

3. Experimental Design

The experiment is designed to test the explanatory power of coarse thinking hypothesis against the benchmark of arbitrage-free pricing. Arbitrage-free pricing is the rational way of pricing a financial asset whereas coarse thinking or pricing with analogy appears to be the most natural way. Specifically, we test for whether a call option is priced in analogy with the underlying asset (*transference* of expected return). We also test for whether changing the similarity affects the analogy (*framing*) as it should if coarse thinking indeed matters.

3.1 Overview

We use an extension of the design used in Rockenbach (2004). In Rockenbach (2004), a number of hypotheses related to mental accounting are tested against the hypothesis of arbitrage-free pricing. Here, we create an extension of the design by varying the striking price in order to evaluate the explanatory power of the coarse thinking hypothesis. We will come back to the significance of similarities and differences between our design and the design in Rockenbach (2004) when we discuss our results.

We conducted 6 treatments, each with 30 participants. Different participants were used in each treatment. In each treatment, there were 60 trials per subject. There was no interaction between participants. Hence, a total of 1800 independent observations per treatment were generated. Participants were given value-neutral labels. That is, terms like call option or the underlying asset were not used. Rather, value-neutral labels (A for the call option and B_1 for the underlying asset) were used. Participants were undergraduate students at ______________________. Each participant was paid at the end of his or her 60 allotted trials. Payoffs were denominated in a fictitious currency called *francs*. An exchange rate of 0.001 Rs/Francs was specified at the outset and was kept fixed throughout the treatments. Average payout per participant was Rs 161. There was no explicit time limit in the experiment. The average duration of a treatment was about 2 hours. The program for the experiment is developed in z-Tree.[3] A calculator was built into the program to assist participants with calculations. A participant can experiment with different values. Decisions in a trial are not finalized till the participant presses a button labeled “Done”. Once finalized, a new trial is presented.

3.2 Treatments

Table 3 shows the parameters used in treatment 1(T1). As can be verified, payoffs from A are equivalent to the payoffs from B_1 minus 65 (the striking price). In treatment 2 (T2), everything remains the same, except that the striking price becomes 70. That is, the payoffs from A in T2 are equivalent to the payoffs from B_1 minus 70. There were 6 treatments corresponding to the striking prices 65 (T1), 70 (T2), 75 (T3), 80 (T4), 85 (T5), and 90 (T6). As explained earlier, participants were given value-neutral labels for assets. They were given the payoff tables without explaining that payoffs from A are

[3] Urs Fischbacher (2007): z-Tree: Zurich Toolbox for Ready-made Economic Experiments, Experimental Economics 10(2), 171-178

equivalent to payoffs from B_1 minus a constant (or 0 in a given state if the payoff from the underlying minus the striking price is negative in that state).

Table 4 shows the payoffs associated with *A* in each treatment. Note, that the treatments can be broadly classified into sets. In set 1, comprising of T1, T2, and T3, payoff in each state is positive. In set 2, consisting of T4, T5, and T6, one payoff (Green State) is 0. Will coarse thinkers show different behavior in set 1 when compared with set 2? In set 1, the analogy with the underlying stock appears stronger (all three states yield a positive payoff for the underlying stock). In set 2, the analogy is somewhat weakened due to the presence of a state with 0 payoff.[4] One expects stronger results for set 1 when compared with set 2 if coarse thinking indeed matters.

Table 3

Parameters for Treatment 1 (T1)

Price	***Type of Asset***	***Red State (R)***	***Blue State (B)***	***Green State (G)***
?	*A*	145	125	15
100	B_1	210	190	80
80	B_2	10	140	90
100	B_3	100	100	100

Table 4

Payoffs associated with *A* in each treatment

	Red State (R)	***Blue State (B)***	***Green State (G)***
T1	145	125	15
T2	140	120	10
T3	135	115	5
T4	130	110	0
T5	125	105	0
T6	120	100	0

[4] The precise measure of similarity between an option and its underlying stock is *delta* (Randleman (2002)). *Delta* ranges from -1 to 1, higher the value of delta, stronger is the similarity. The delta value in the first set is 1 where the *delta* in T5, and T6 is 0.96, and 0.92 respectively. *Delta* with respect to B2 is either zero or negative in all treatments whereas the *delta* with respect to B3 is negative in all treatments. It is clear that there is no similarity between the call option and B2 or B3. Similarity exists between the call option and B1 and is stronger in set 1 when compared with set2.

Table 5 shows the predicted prices of asset A corresponding to each treatment under arbitrage-free pricing as well as coarse thinking.

Table 5

Treatment	***Arbitrage-Free Pricing (AFP)***	***Coarse Thinking (CT)***
T1	35	59.38
T2	30	56.25
T3	25	53.13
T4	20	50
T5	19.22	47.92
T6	18.43	45.83

3.3 Implementation of the Experiment

In each treatment, each subject participates in 60 individual trials. Each subject acts individually and there is no communication between participants. Each participant's task is to allocate 1000 francs between four assets; A, B_1, B_2, and B_3. Specifically, in each trial, every participant decides how many units of A, B_1, and B_2 to buy or short. The remaining amount is invested in B_3. Participants are told that each state is equally likely to occur. As demonstrated in Bossaerts (2004), often in experiments, there may be a gap between announced and perceived uncertainty. To eliminate this possibility, algorithm for drawing the state is clearly explained to the participants. Participants are told that, at the end of each trial, a number will be randomly drawn from a discrete uniform distribution ranging from 1 to 90. If the number drawn is between 1 and 30 (including both limits) then the state realized is Red, if the number if between 31 and 60, the state is Blue, and if the number is between 61 and 90, the state is Green.

The prices of B_1, B_2, and B_3 are kept constant at 100, 80, and 100 respectively throughout the experiment. At the beginning of each trial, the price of A is randomly drawn from a uniform distribution with the lowest payoff as the lower limit and the highest payoff as the upper limit. This fact is known to every participant. As an example, in T1, the lower limit is 15 and the upper limit is 145. In T1, each time the price of A differs from 35, an arbitrage opportunity arises. Three constraints are imposed on the choices of each participant. Firstly, he or she cannot short more than 10 units of A per trial. Obviously, if A is overpriced, a rational participant would want to short an infinite amount of A. Consequently, a restriction on the number of units that can be shorted is needed. Secondly, we impose the following bankruptcy condition; net payoff in each state must be positive. This constraint is needed to guarantee a non-negative payoff to each participant. Finally, asset A must be a part of the portfolio in every trial. Since A will be overvalued in some trials and undervalued in others and our objective is to see how participants respond, it makes sense to impose this condition.

The concept of shorting or selling without owning is typically not clear to many people. We took extra care in explaining the concept. Participants reluctant to sell because of unfamiliarity with short-selling would bias our results upwards. Participants were shown one example explaining why selling (shorting) an overvalued asset may be a good idea and another example explaining why buying an undervalued asset may be a good idea.

Once a participant has allocated funds among the four assets, a state is randomly (following aforementioned procedure) drawn and the payoff is announced to him or her. At all times, the history of trials is available to each participant for review. That is, each participant can see his or her past decisions as well as payoffs.

4. Results

Before discussing our results, it is useful to discuss the experiment in Rockenbach(2004). Rockenbach (2004) tests a number of hypotheses related to mental accounting against the benchmark of arbitrage-free pricing. In that experiment, participants were presented with a call option along with the underlying stock and a bond. The questions of interest were: Are all three instruments considered jointly in a single mental representation as required by arbitrage-free pricing? Are there other mental representations with better explanatory powers? Possibilities tested were, a mental representation including the call and the underlying stock, a mental representation including the call with the bond, or an isolated representation for the call option. Rockenbach (2004) finds that these other mental representations have greater explanatory power than the hypothesis of arbitrage-free pricing. Interestingly, a mental representation including the call with the underlying stock outperformed others.

In the context of coarse thinking, a mental representation or account as used in Rockenbach (2004) can be thought of as an exogenously specified category. However, leaving the matter here is unsatisfactory for a number of reasons. Firstly, it begs the question of where do these categories come from. In the absence of endogenization of categories, an alternative to the arbitrage-free pricing cannot be properly specified. Secondly, why did the mental representation including the call with the underlying stock outperformed others? Was this pure chance? Rockenback (2004) used a call option that yielded a positive payoff in all states. That is, the call option considered was highly similar to the underlying stock (*delta* =1). Do the results change if a call option less similar to the underlying stock is used (*delta*<1)? Finally, in the absence of a theory explaining the categories, tests of the notion of mental accounts require additional ad hoc assumptions. In particular, risk-neutrality was assumed in Rockenbach (2004). It naturally begs the question of whether the results carry over to more general preferences. Also, Rockenbach (2004) tests one specific application of the portfolio replication argument called the binomial option pricing model. The portfolio application argument is general and is also applicable to situations that admit more than two states. Here, we test the portfolio replication argument against the coarse thinking hypothesis when there are three states.

The hypothesis of coarse thinking has the potential of addressing these concerns. The notion of *framing* allows for endogenization of categories. In the experiment, we test for *framing* by gradually altering the similarity between the call option and the underlying stock over 6 treatments. Analogy based pricing should vary as the similarity is varied. If coarse thinking indeed matters then some sort of a "structural break" should be seen as we move from set 1 (T1, T2, and T3) to set 2 (T4, T5, and T6). In this context, the experiment in Rockenbach (2004) can be considered roughly equivalent to a treatment belonging to set 1. The notion of *transference* where an attribute from a situation is transferred to another co-categorized situation is independent of risk-preferences, thus, increasing the generality of results. Furthermore, the coarse thinking hypothesis has the potential of integrating different strands of literature in a comprehensive framework. As one example, Mullainathan et al (2008) provide possible explanations for a number of intriguing observations in industrial organization and finance. As another example, results in Rockenback (2004) can be viewed as a special case of coarse thinking.

We follow Rockenbach (2004) in defining the separating price as follows. A separating price is a price P below which a participant buys the option and above which the participant sells the option. That is, it is the price that separates buying from selling. We do not directly observe separating prices, however, we do observe the decisions of participants (whether they buy or sell at a certain price). Separating prices can be statistically inferred from the observations as follows. Denote the price that a participant i faces in a trial t by A_{it}. For treatment 1, suppose $P \in \{15,............,145\}$ is fixed and is the separating price.[5] Subject i in trial t violates the assumption of the separating price if he or she fails to buy when $A_{it} < P$ or fails to sell when $A_{it} > P$. Whenever there is a violation, we calculate the squared deviation as $D(P) = (A_{it} - P)^2$. $P \in \{15,............,145\}$ that minimizes the sum of squared deviations is set as the separating price for the subject i.[6] We considered 4 phases for each subject in every treatment; trials (1-60)/overall, trials (1-20), trials (21-40), and trials (41-60). For each subject, a separating price is calculated for each phase. Table 6 shows the average separating price (average of 30 subjects) in each treatment for each phase. It also shows the difference (in absolute value) between the average separating price over 60 trials and the arbitrage-free price (|Overall – AFP|) as well as the difference between the average separating price and the coarse thinking price (|Overall – CT|). As can be seen from the table, price with coarse thinking is much closer

[5] For T2, the range is from 10 to 140. For T3, the range is from 5 to 135. That is, the payoff in state G is the lower limit and the payoff in state R is the upper limit in each treatment.

[6] In case of a connecting region with the lowest squared deviation, an average over the region is taken. It is easy to see that the points with the lowest deviation must be connected if there are multiple such points.

to the average separating price when compared with the arbitrage-free price in all treatments. [7]

Table 6

Average Separating Price

Treatment	***1-60 (Overall)***	***1-20***	***21-40***	***41-60***	***|Overall-AFP|***	***|Overall-CT|***
T1	65.19	69.74	63.85	64.92	30.19	5.81
T2	62.34	65.88	61.70	60.57	32.34	6.09
T3	60.03	62.34	60.85	59.61	35.03	6.90
T4	59.27	61.78	58.16	57.13	39.27	9.27
T5	59.42	62.23	59.64	58.44	40.20	11.5
T6	57.96	59.11	57.74	57.16	39.53	12.13

Next, we formally test for the closeness of price with coarse thinking with the average separating price as observed in our experiment by the Wilcoxon signed-rank test:

H_0: *The differences (in magnitudes) between the average separating prices and the corresponding prices predicted by coarse thinking hypothesis are equal to the differences (in magnitudes) between the average separating prices and the corresponding arbitrage-free prices.*

H_α **:** *The differences (in magnitudes) between the average separating prices and the corresponding prices predicted by coarse thinking hypothesis are smaller than the differences (in magnitudes) between the average separating prices and the corresponding arbitrage-free prices.*

[7] To convince ourselves that the notion of average separating price is indeed an accurate description of behavior, we did the following. Treatment median of (per trial) average squared deviation from the separating price is calculated for each experience phase. In all treatments, the squared deviation from the separating price decreases with experience as confirmed by Friedman test. Hence, the behavior of participants becomes more and more in line with their respective separating prices as participants gain experience.

Wilcoxon test statistic has a value of 21 with a p-value of 0.025. Clearly, the coarse thinking hypothesis outperforms the hypothesis of arbitrage-free pricing in our experiment.

Next we consider whether there is a significant difference in the performance of coarse thinking hypothesis (*transference*) between treatments in set 1 (T1, T2, and T3) and treatments in set 2 (T4, T5, and T6). The factor that differentiates the two sets is the zero payoff in the green state in all treatments that belong to set 2. The presence of a zero payoff reduces the similarity between the call option and the underlying stock making their co-categorization (consequently *transference*) less likely. The average difference between the predictions of coarse thinking hypothesis and the observed average separating prices in set 1 ((5.81+6.09+6.90)/3) is 6.27. This difference is smaller than the corresponding difference in set 2, which is ((9.27+11.5+12.13)/3) 10.97. Table 7 presents the mean squared errors between the separating price and the coarse thinking price in treatments in set 1 and set 2. These errors are calculated as follows. For each experience phase, and for each subject in each treatment, the squared difference between the separating price and the coarse thinking price is calculated. The squared differences so calculated are added for all 30 subjects in each treatment. The average squared differences are reported for set 1 and set 2 in table 7.

<u>Table 7</u>

Experience Phase	***MSE in Set 1 (T1, T2, and T3)***	***MSE in Set 2 (T4, T5, and T6)***
1-60	14538.097	22777.819
1-20	21849.162	26212.569
21-40	18991.964	24585.582
41-60	18571.788	25037.523

As can be seen from table 6, the behavior of participants is more consistent with the hypothesis of coarse thinking in set 1 when compared with the behavior of participants in set 2. This is in line with expectations if coarse thinking hypothesis is indeed true. In set

2, the analogy between a call option and the underlying stock is considerable weakened due to the presence of a zero payoff in one state.

We have seen that the coarse thinking hypothesis clearly outperforms the hypothesis of arbitrage-free pricing. We find evidence indicating that coarse thinking matters for option pricing in a controlled laboratory experiment. Coarse thinking is an interesting hypothesis that demands greater empirical scrutiny. This paper is a step in this direction.

5. Conclusion

Economics is primarily a study of how people make decisions. The traditional paradigm that assumes that people act as if they are emotionless geniuses while making decisions, has now given way to alternative approaches that admit limits on reasoning ability. However, saying that there are limits on reasoning ability is far from enough. The actual challenge is to provide a theory of where do these limits come about. An associated challenge is to show empirically that these limits actually matter in decision making. Coarse thinking hypothesis is a reflection of ideas from such diverse fields as psychology, linguistics, marketing, advertising, and politics. The essential idea is that people put situations into categories and then apply the same model of inference to all situations within a category. That way, the value assigned to an attribute in a given situation is affected by the values of the concerned attribute in other co-categorized situations. We experimentally evaluate this idea in the context of option pricing. We tested whether coarse thinking or analogy based pricing matters for option pricing. Specifically, we tested whether the attribute of price is affected by coarse thinking. We find that indeed coarse thinking affects the way a call option is priced.

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